AN EXPERIMENTAL STUDY OF WIRE DRAWING

By

M. CHANDRA PRAKASH

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DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

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AN EXPERIMENTAL STUDY OF WIRE DRAWING

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

By

M. CHANDRA PRAKASH

to the
DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR
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CERTIFICATE

This is to certify that the work entitled "AN EXPERIMENTAL STUDY OF WIRE DRAWING" by [illegible] Chandra Prakash has been carried out under our supervision and has not been submitted elsewhere for a degree.

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M. Chandra Prakash

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LIST OF FIGURES

ABSTRACT

In the present work, wire drawing experiments have been carried out on a vertical wire drawing machine under dry conditions using specially made split dies and irradiated dies. The volumetric wear of the die has been evaluated by examining the interface of the split die. The drawing and separating forces have been measured with the help of a specially designed dynamometer which was capable of measuring these forces independently. The diameter of drawn wire was also measured at regular intervals.

The average coefficient of friction was calculated using an indirect method. The examination of various parameters indicates that die life could be evaluated in terms of volumetric wear or dimensional accuracy of drawn wire.

For measuring the volumetric die wear, the γ-γ coincidence technique appears to be quite sensitive and gives result which agree well with those obtained using split dies.

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CHAPTER - I

INTRODUCTION AND REVIEW OF PREVIOUS WORK

1.1 INTRODUCTION :

The principal function of wire drawing is to make wire of a specified size and surface finish. This is done by pulling the wire through a die with a tapered bore [1]. In such a process considerable amount of die wear occurs. To study the wear of these dies, it is desirable to have a rapid method of assessing the die wear; so far two methods have been tried. The first involves the use of rapidly wearing dies [1]. It is being justified on the grounds that, basically, the mechanism of wear is the same no matter what material the die is made of. It is a sound method for rough and qualitative comparison. In the second method, radioactive-tracer techniques are employed. Small quantities of wear can be measured by the extremely sensitive radiotracer method. There is a need to verify the accuracy of tracer technique, and this has led to the present investigation. Considering the above facts H.S.S. dies were used under dry working conditions to measure die wear by conventional technique using split dies and the radio-tracer method.

1.2 LITERATURE SURVEY :

Various investigations have been carried out to study the important parameters affecting the mechanics of wire drawing

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process. Yang [2] had carried out experimental investigation to evaluate the coefficient of friction in wire drawing using split dies. MacLellan [3] and Wistreich [4] also studied the effect of coefficient of friction in wire drawing. Effect of die profile on the drawing stress was studied by Hu [5] using straight, concave, convex and bell shaped die profiles. Bell shaped die gave the lowest drawing stress value and the most uniformly distributed pressure and frictional force. The use of strain gauges on the outside die surface provides a method for recording the sum total of effects contributing to die pressure. Majors [6] had used this technique to find the coefficient of friction in cold drawing.

Effects of friction at the tool-work interface during the deformation process have been studied by many researchers, and the characteristics of the factors that influence various problems such as tool load, material flow, surface finish of workpiece and tool life have been clarified. Experiments have also been carried out [7] to examine the frictional surface during the drawing process. These experiments clearly show the welding region during drawing of mild steel.

Changes in workpiece temperature during drawing are frequently of interest. Large die/wire interface temperatures are likely to hinder lubrication. Differences of temperature between outer surface of wire and the core are the source of residual stress in drawn wires. In ferrous and some other alloys high temperatures may speed-up age hardening and thereby lowering

the ductility of wire. Pawelski et al. [8] developed methods for measuring temperatures at several locations in the deformation zone and investigated the effects of reduction, drawing speed, lubrication and rod geometry on the temperature distribution.

In the deformation zone material starts flowing when it reaches plastic state and this plastic formation results in strain hardening and residual stresses. With the increase in drawing speed the rate of straining of the material will increase. The wire drawing operation is usually carried at high speeds and therefore, high strain rates are involved in the process. Alder et al. [9] have reported the strain-hardening effects for various materials and calculated the strain rate sensitivity coefficients for a range of temperature and reduction in area.

Caddel and Atkins [10] extended the Sach's stress-balancing equation [11] for drawing to include the effects of strain hardening and redundant deformation. The improved analysis leads to families of curves for the relationship between drawing stress and die angles. They also developed empirical factors which predict the amount of redundant strain from a knowledge of the flow stress of the material before deformation, the work hardening coefficient, the reduction, and the die angle [12]. Their equation indicates that redundant work is more sensitive to the strain hardening coefficient than to the strength in the unstrained state. Johnson and Rowe [13]

[redacted]

have also investigated this problem by comparing measured drawing stresses with the analytical estimates. They have concluded that neither friction nor strain hardening has much effect on redundant work.

Surface finish, a characteristic which can affect the service performance of cold formed articles is beginning to receive more attention. Apparently, the roughness measured in the direction of strain increases with strain and the changes are larger for compressive than for tensile deformation. Oyane and Osakada [14] suggest a simple model for explaining the changes in finish on free surfaces and on surfaces contacted by tooling.

Recently some authors [15, 16] have tried to make wires, in which cutting and forming are combined into one process. A chip of square cross-section was cut and converted into circular wire using a single die. It was found that drawing forces required for this conversion are higher than for a conventional round to round reduction. The drawing force required in this new process were 1.4 to 2.8 times that required for the conventional process.

The mechanism of wear in carbide dies has been studied by means of metallographic examination of the profiles of worn dies [1], spectrographic analysis of used wire drawing-soap and by observing the disposition of wear debris attached to the drawn wire and originating from radioactive dies. It appears from the presence of radioactive smudges of cobalt on the wire

[redacted]

that microscopic welding occurs most readily between the cobalt matrix of the die and the metal of the wire. The carbide grains are thereby exposed and are polished away, broken or torn out.

The intensity of wear varies markedly along the die/wire interface, it is least in the middle, rather more at the exit, and by far the greatest at the entry. The difference in the microscopic appearance of the worn die surface at entry and elsewhere are such that one is led to suspect that a different mechanism of wear is at work at the entry to the die, where a deep and clearly defined annular crater is formed, commonly referred to as 'ringing'. Wistreich [1] has suggested that this ringing is analogous to the 'Brinelling' wear of ball races; i.e., the plane of impingement of wire on die is thought to oscillate about a mean position because of irregularities of size and vibration of the wire.

A few authors have studied die wear using radioactive dies. Sutton et al. [18] studied the wear of wire drawing dies by surface activation method. Experiments were carried out on a draw bench and G.M. Counters and auto-radiograph methods were used. Jaoul [18] used this method for a particular application, namely the wear of the die face during hot extrusion of steel. The accuracy of measurement of die wear was of the order 10^{-4} grams. Determinations of radioactivity were made on several sides of the extruded bars, giving average wear values under normal conditions. In some cases a certain die shape wore by a

[redacted]

definite amount per metre, while on other shapes wore to an extent that was hardly measurable. The influence of temperature, ingot surface, rate of extrusion, die surface, lubricant, etc. on die wear was evaluated. Askouri et al. [19] had studied the die wear using on-line wear monitoring by surface activation. The dies were activated to a depth of about 70 μm in the bearing region. The decrease in die activity was used to estimate the diametral increase in the die bore. They carried out the experiments on new and resized dies. It was found that the new die wore at a steady rate where as the resized die wore at a non-uniform rate in the bearing zone.

Chawla et al. [20] have applied γ-γ coincidence technique in metal cutting for obtaining absolute flank and crater wear volumes from irradiated high speed steel tools using Co^{60} as the radiotracer. Consistent absolute results were obtained irrespective of the exact counting geometry offered by a given chip sample.

1.3 PRESENT WORK :

In the present work an attempt has been made to evaluated the die wear in wire drawing using split dies and irradiated dies. The die wear obtained by both the methods are compared. The effect of drawing speed on die wear, drawing forces, seperating forces, diameter of wire is studied.

[redacted]

CHAPTER - II

EXPERIMENTAL SET-UP AND EVALUATION OF DIE WEAR

2.1 EXPERIMENTAL SET-UP :

The details on measurement of die wear in wire drawing, measurement of separating and drawing forces, measurement of wire diameter after drawing are given in this chapter. The volumetric die wear has been evaluated using both conventional and radioactive methods. The technique involved the drawing of wire to a certain length and measuring the important parameters. The values of the coefficient of friction was evaluated using an indirect method. The related pattern of various parameters during drawing are thus obtained.

2.2 WIRE DRAWING MACHINE :

The machine used was a vertical wire drawing machine supplied by Machinary Manufacturing Corporation Limited, Calcutta. (The details of the machine are given in Appendix I) Here the capstan rotates with respect to a vertical axis and the speed of the capstan can be changed by a gear box attachment providing drawing speeds upto 77.75 m/min.

2.3 DYNAMOMETER :

In order to measure the separating and drawing forces simultaneously during drawing, a special type of disc dynamometer was used. The details of the dynamometer are shown in Fig. 2.1.

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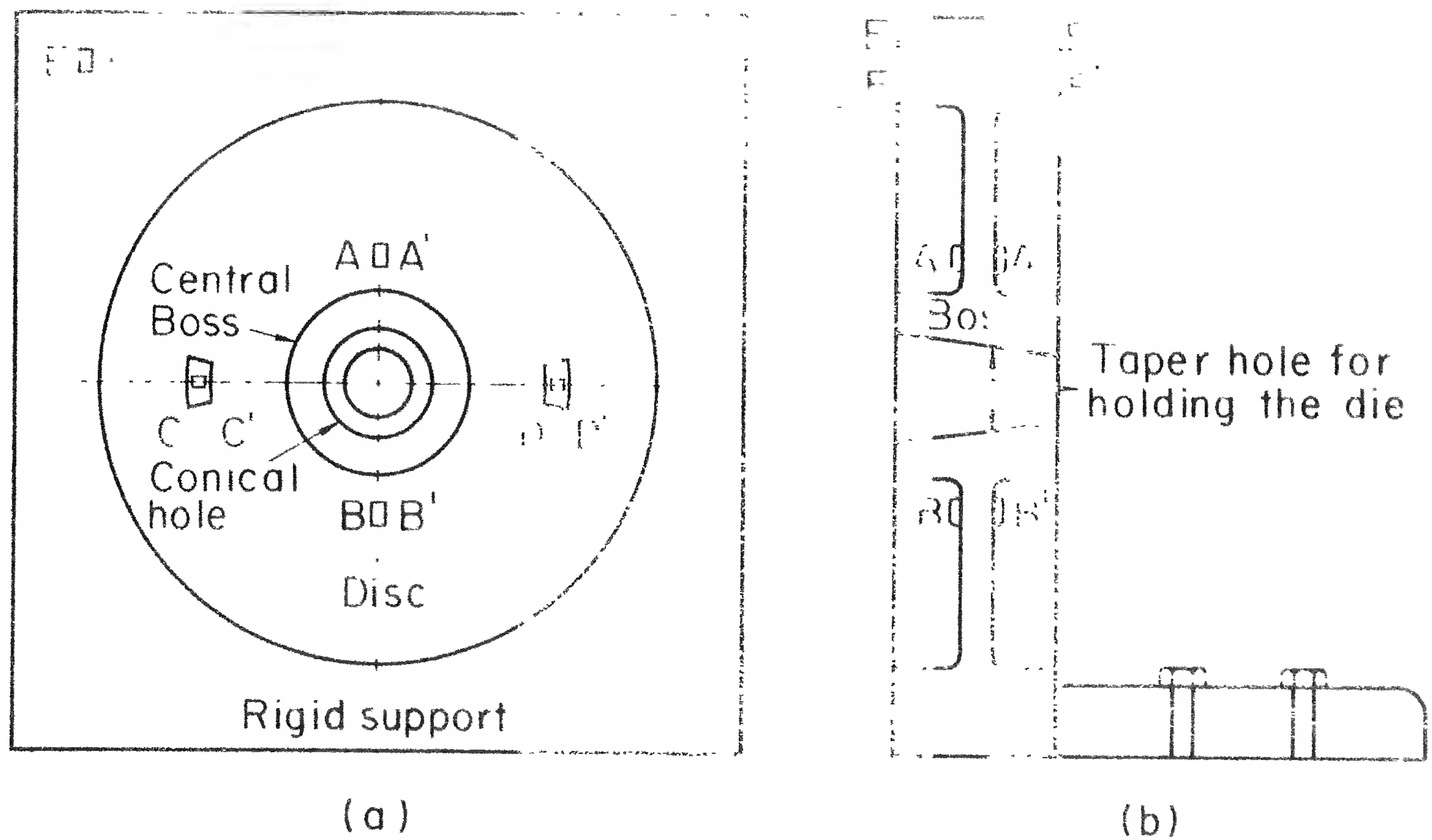

Fig. 2.1 Details of the disc dynamometer

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It consists of an elastic circular disc which is supported at its periphery. A central boss with circular tapered hole is installed in the middle of disc. This tapered hole is used to hold the split die holder.

Strain gauges AA'BB' are used for measuring the drawing force while gauges CC'DD' measure the separating force. EE'FF' are dummy gauges used to complete the bridge circuit for separating forces.

The drawing force deforms the disc into a spherical form as shown in Fig. 2.2a. This causes an imbalance in the strain gauges AA'BB' which is recorded. For measuring the separating force, strain gauges have been inserted in niches. The separating force reduces the thickness of the disc Fig.2.2b and hence causing imbalance in gauges CC'DD'. The circuit diagrams for the measurement of forces are shown in Fig. 2.3.

2.4 CONSTRUCTION OF THE DYNAMOMETER :

A mild steel square plate of 320X320X12.5 mm was taken and the intersection of diagonals was marked on both sides. Two circles of radius 40 mm and 100 mm were marked. The material was removed from both the sides till the thickness reduced to 6 mm. A tapered hole was made in the central boss. The niches were made by removing the further material from both the sides, till the thickness reduced to 2 mm. Semiconductor strain gauges were used as shown in Fig. 2.1. The final shape of the dynamometer is shown in Fig. 2.4.

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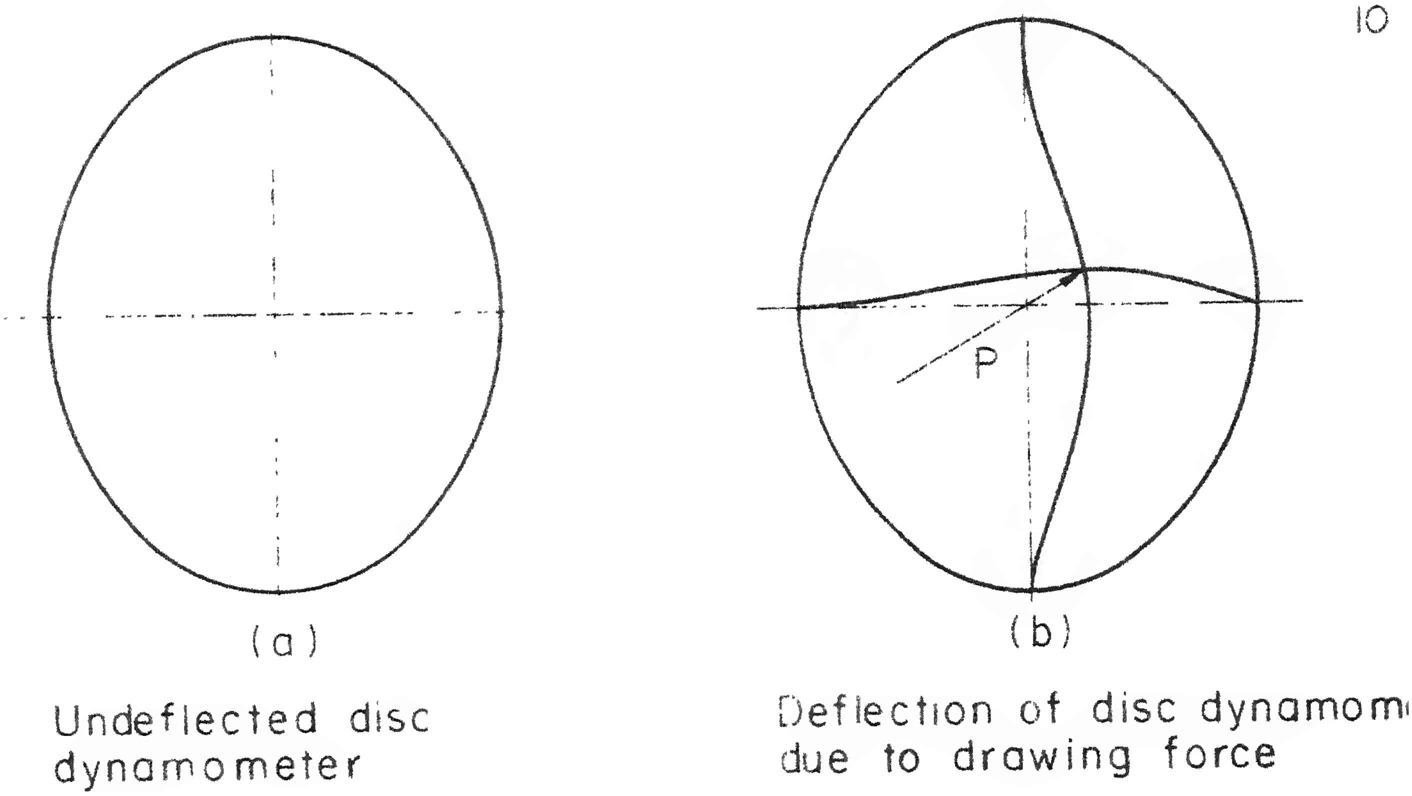


Fig 2.2 a

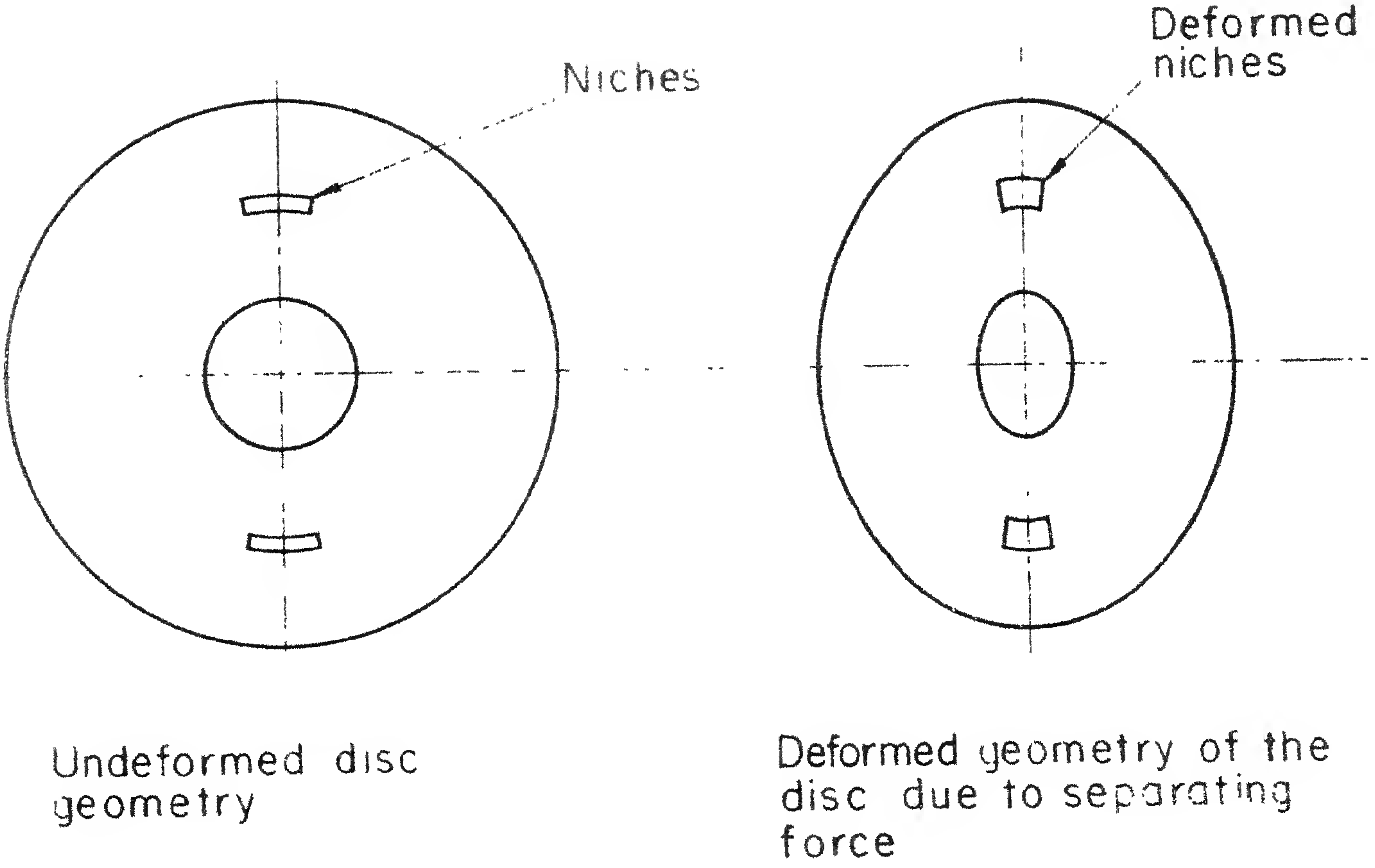
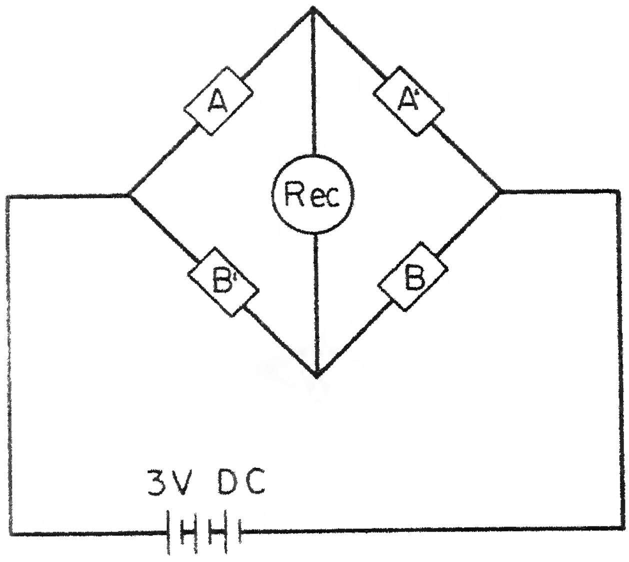
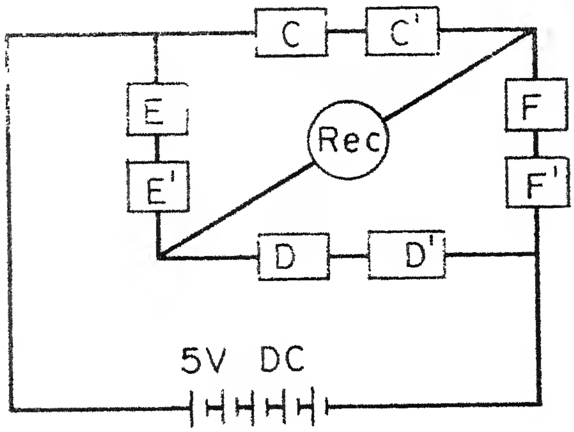


Fig.2.2 b



3a . Connection and operation of the strain gauges for the drawing force



3b Connection and operation of the strain gauges for the separating force

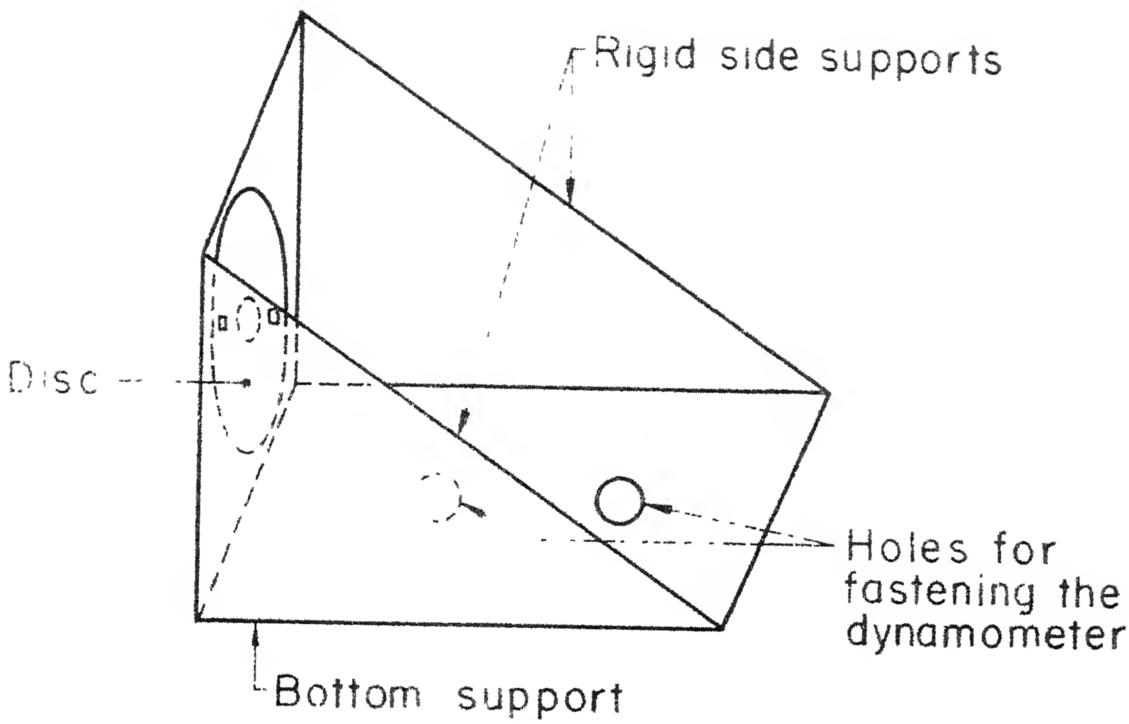


Fig 2.4 Schematic view of the disc dynamometer

2.5 CALIBRATION OF THE DYNAMOMETER :

To measure the drawing force the dynamometer disc was kept horizontal on four equal supports at the corners. The connections were made as shown in Fig. 2.3 and an excitation voltage of 3 V d.c. was supplied through a voltage source. By keeping dead weights on the central boss in steps of 10 kgs. the deflections on the recorder were noted. The dead weights were removed in steps of 10 kgs. This gave the plot for drawing force.

For separating force the dynamometer was kept vertical on lathe bed such that the axis of the tapered hole was perpendicular to the cross-slide movement direction. Two hooks were put in the tapered hole facing opposite to each other. One end the hook was fixed rigidly in the chuck and other end of the other hook was connected to the tool post through a spring balance. The cross-slide was moved to apply the separating force and the calibration was done. The exciting voltage of 5 V d.c. was supplied for measurement of split force. The calibration curves for drawing and separating forces are shown in Fig. 2.5.

2.6 DYNAMOMETER INSTALLATION :

The dynamometer was fixed on the base plate of the wire drawing machine. While fixing care was taken to keep the axis of the die tangent to the circumference of the capstan. Out of alignment may cause uneven wear on two halves of the

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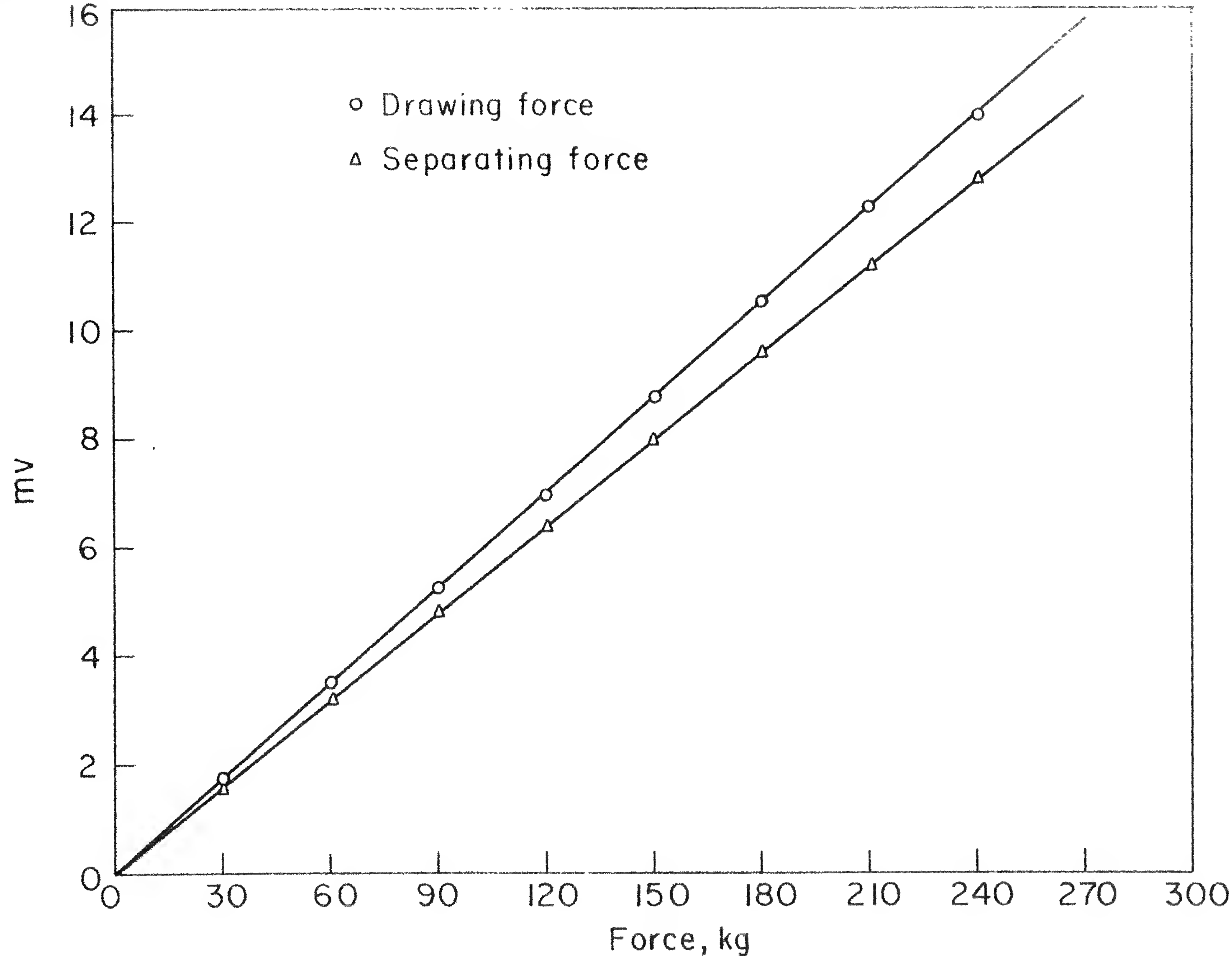


Fig.2.5 Calibration curve of the dynamometer

[redacted]

split die and error in separating force may occur and some times even the wire may break.

2.7 RECORDING OF FORCES :

The dynamometer output signal was connected to a two channel Encardio-Rite recorder. Both drawing force and separating force were continuously recorded, and there values were obtained from the calibration curves.

2.8 SPLIT DIES AND DIE HOLDER :

High speed steel was used for making split dies. The H.S.S. composition was 18 % W, 4 % Cr, 1 % V, 5 % Co and the remaining Iron and Carbon. The split die specifications were : exit diameter = 1.844 mm, bearing length = 2.75 mm and semi die cone angle = 3°. The outside diameter of split die was smaller than the tapered hole in the central boss of the dynamometer. A tapered split die holder was made with mild steel to hold the split die in the boss of the dynamometer.

2.9 WIRE MATERIAL :

The wire material used was 2 mm diameter mild steel wire. The main consideration in selecting this material was to get measurable die wear after drawing a reasonable length of wire (say 1000 meters) using HSS die under dry working conditions.

2.10 MEASUREMENT OF DIE WEAR :

Volumetric wear of the die could be calculated by knowing the diameters before and after the drawing at different sections along the die. Since the split dies were used for the experimental purpose, it was easy to measure these changes in the diameters.

A 'V' block was mounted on a table which could move in two perpendicular directions in the same plane with the help of micrometers and one half of the split die was kept in 'V' groove. A transducer was attached to another table which could move upwards and downwards with the help of micrometer. Any deflection of transducer can be seen on the scale of LVDT (specifications in Appendix II). The transducer was brought down so that it touches the surface of the split portion of the die. By moving the table horizontally, it was possible to make the split surface parallel to the transducer. Measurements were taken at different sections of the die and the radius was calculated. After drawing the wire also, measurements were taken as explained above and the change in diameter was calculated to find the volumetric wear.

The typical die profile before and after drawing is shown in Fig. 3.1b. The volumetric wear was calculated using the following equations.

$$\text{Volume } V_1 = \frac{\pi}{24}\left[D_b^3 \operatorname{Cot}\alpha - D_a^3 \operatorname{Cot}\alpha + 6D_a^2 L\right] \quad \ldots 2.1$$

[redacted]

$$\text{Volume } V_2 = \frac{\pi}{24}\left[(D_d^3 - D_c^3)\,\text{Cot}\alpha_1 + (D_b^3 - D_d^3)\,\text{Cot}\alpha_2\right] \quad \ldots 2.2$$

$$\text{Volumetric wear} = V_2 - V_1 \text{ mm}^3 \quad \ldots 2.3$$

2.11 MEASUREMENT OF DIAMETER OF WIRE :

The diameter of wire after drawing was measured with the help of a optical shadowgraph.

2.12 EXPERIMENTAL PROCEDURE :

The wire was pointed to a diameter less than 1.844 mm for a length of one to two meters. The split die and split die holder were kept in the tapered hole of dynamometer. The wire was taken through the die and the gripping of the wire was done by using a pulling dog which was fixed on the capstan. All the connections were made and exciting voltage were given through the power supply. Capstan was rotated with hand to give the initial tension in the wire. Gear box was set at the proper speed. A stop watch was used to note down the time of drawing. The machine was started with the help of foot switch and after some time, it was put in continuous running.

After drawing for certain time the machine was stopped and the time of drawing was recorded. The die was taken out and wear measurements were taken. The process was continued till the die was completely worn out. Using other dies of same specifications, experiments were repeated at different drawing speeds.

2.13 EXPERIMENTAL SET-UP FOR NUCLEAR EXPERIMENT :

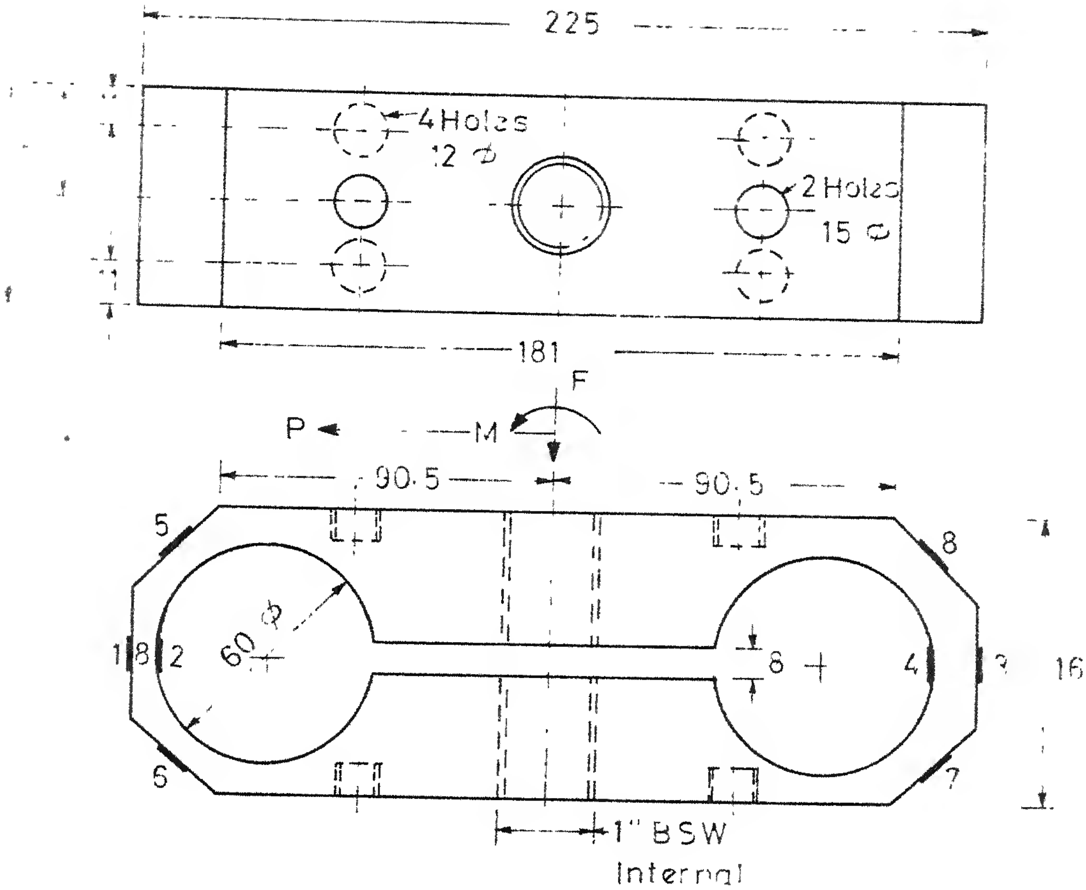
In this experiment the same wire drawing machine was used as that of conventional experiment. Here the die is irradiated to study the ^{60}Co gamma-rays, so it requires special shielding attachment.

An extended octagonal ring dynamometer (Fig. 2.6) was used for measuring the drawing force. This set-up was earlier used by Jajoo [21]. Before using the set-up, the calibration was checked (Fig. 2.7). The force was recorded continuously using a pen recorded. The complete set-up is shown in the work done by Jajoo [21].

Measurement of wear was taken at different lengths of drawn wire. By counting the number of revolutions on the rewinding drum, the exact position of wire can be noted. The samples for counting the gamma activity were made by taking one meter length of wire.

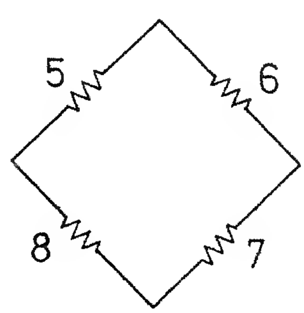
2.14 SAFETY PRECAUTIONS :

The handling of irradiated dies require good shielding. A trolley was made on which lead bricks were kept shielding completely the dynamometer. The thickness of the shield was calculated by taking into consideration the safe limits of exposure specified by ICRP guide lines (2.5 m rem/hr). Other precautions such as covering the floor area by removable rubber sheets, reducing the time for experiment, using of hand gloves etc. were also taken.



(a) DYNAMOMETER

Dimensions are in mm



(b) P-Circuit

FIG. 2.6 DYNAMOMETER & P-Circuit

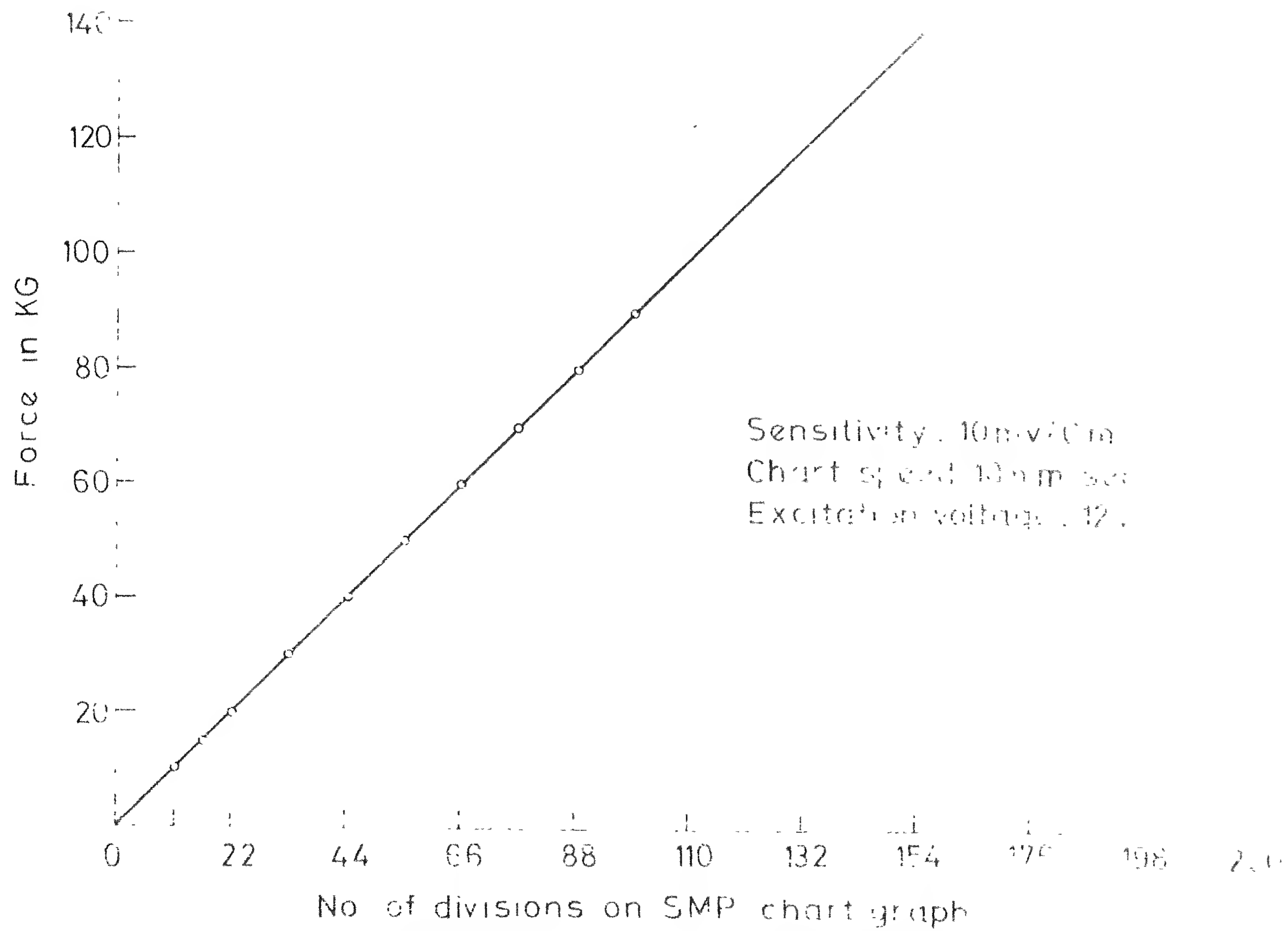


FIG 2 7 CALIBRATION CHART OF DYNAMOMETER

2.15 SAMPLE MAKING :

Samples were made by taking one meter wire at different lengths. This one meter length wire was cut into 20 pieces and sealed by a perspex sheet and mounted by cello-tape. Samples were numbered for identification.

2.16 NUCLEAR SET-UP :

For the present work γ-rays were detected by NaI scintillating detectors. Absolute activity was measured by γ-γ coincidence method which needs two detectors and measures two gamma peaks of 1.17 MeV and 1.33 MeV of cobalt.

2.17 γ-γ COINCIDENCE TECHNIQUE :

The volumetric wear of wire drawing die was found with the help of γ-γ coincidence technique. This technique needs a radio-tracer which emits more than one γ-rays at different levels. Co^{60} emits two γ-rays one at 1.17 MeV and the other at 1.33 MeV. Scintillation detectors are more efficient to measure γ-rays. So two NaI detectors were taken and were set, such that one will measure 1.17 MeV, the other 1.33 MeV levels. The absolute activity can be calculated by the equation.

$$N = \frac{C_1 C_2}{C_{12}} \quad \mu Ci$$

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where C_1 = count rate of detector 1

C_2 = count rate of detector 2

C_{12} = coincidence count rate

From absolute activity values the volumetric wear of die was calculated and error calculations were given in Appendix III.

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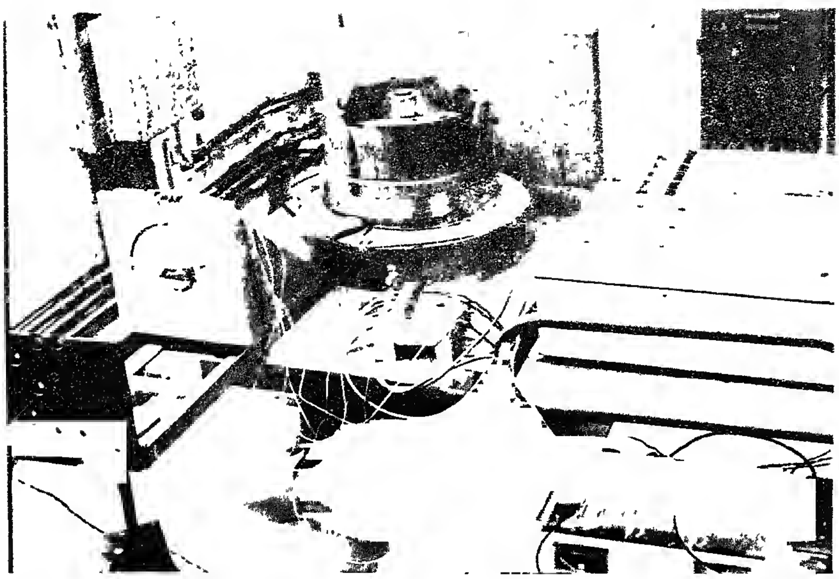

EXPERIMENTAL SET-UP IN WIRE DRAWING

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CHAPTER - III

RESULTS AND DISCUSSION

Wire drawing experiments have been carried out at three different drawing speeds (31.77 m/min., 50.09 m/min., and 77.75 m/min.) using split dies and at one drawing speed (50.09 m/min.) using irradiated die. Split die experiments have been carried out to study the effect of drawing speed on various drawing parameters such as die wear, forces, dimensional accuracy of drawn wire etc. In the radio-tracer experiment the aim was to verify the validity and accuracy of the technique of evaluating die wear by comparing the wear values with those obtained using unirradiated split dies. Because of certain difficulties in obtaining irradiated dies from BARC, only one drawing speed could be used. All the experiments have been conducted using H.S.S. dies of the following specifications:

Entry diameter	=	2 mm
Exit diameter	=	1.844 mm
Die Semi Cone angle	=	3^{o}
Bearing length	=	2.75 mm

The wire material was mild steel with 2 mm diameter.

In order to see the wear pattern of the die, the bore at different sections along the axis of used dies have been

traced. A typical result is shown in Fig. 3.1a. The die bore appears to remain almost circular at all sections but the diametral wear was different at different sections. This indicates that the wear is not uniform throughout the length of the die. This agrees with the earlier results of Wistreich [1]. Fig. 3.1b shows the die bore profile along the axis of the die. Such a profile is indicative of the variation in the normal pressure at the interface. This wear pattern will also be influenced by the interface temperature which also varies along the die length.

The wear of the die has been evaluated in terms of volume of material lost and was calculated using equation (2.3). Fig. 3.2 gives the variation in die wear during continuous drawing. It shows that the wear rate is high in the initial stage but decreases significantly during subsequent drawing. This reduction in the wear rate may be due to material deposition on the die. Further as the drawing process continues the exit diameter increases, thereby reducing the effective reduction in area of the wire which in turn affects the wear rate. It can also be observed that the speed of drawing effects the wear-rate (Fig. 3.2). Although the volumetric die wear increases with increase in drawing speed, the pattern of the wear curves remains almost the same in the range of speeds investigated. In actual practice, the drawing speeds for mild steel wires for 15 % reduction is generally

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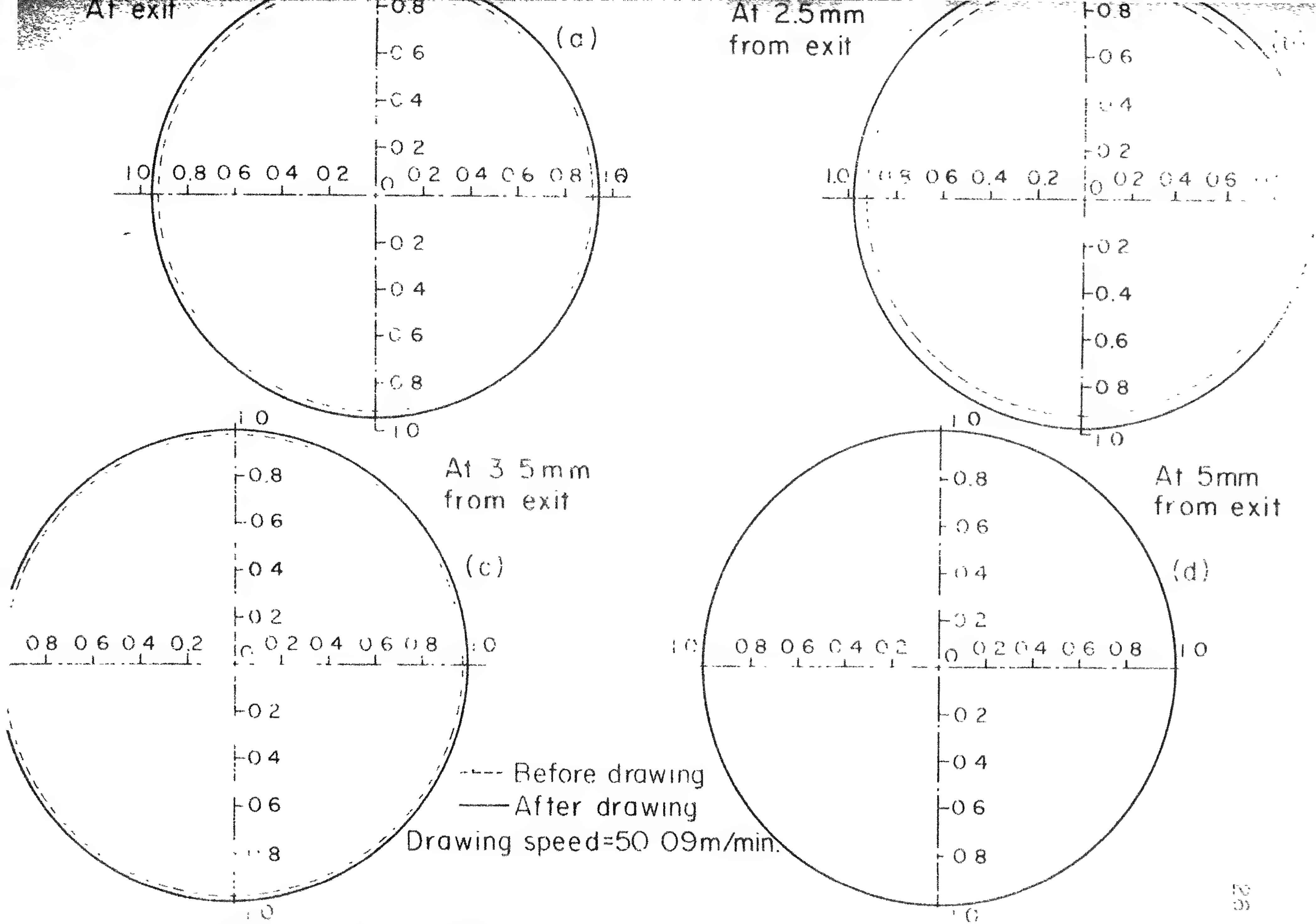

Fig.3 l a Die profile at different sections

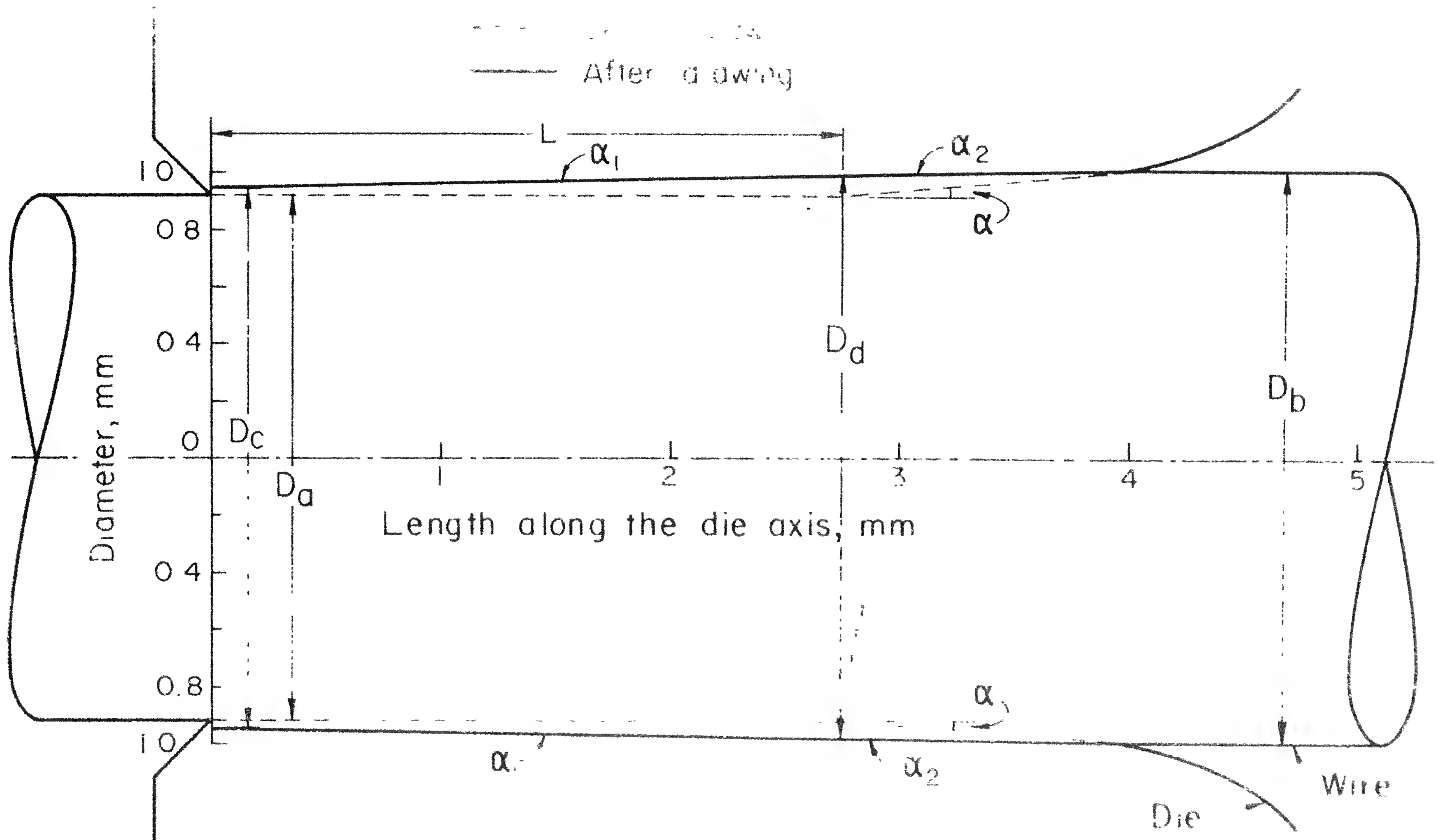

Fig 31 b Shape of die before and after drawing

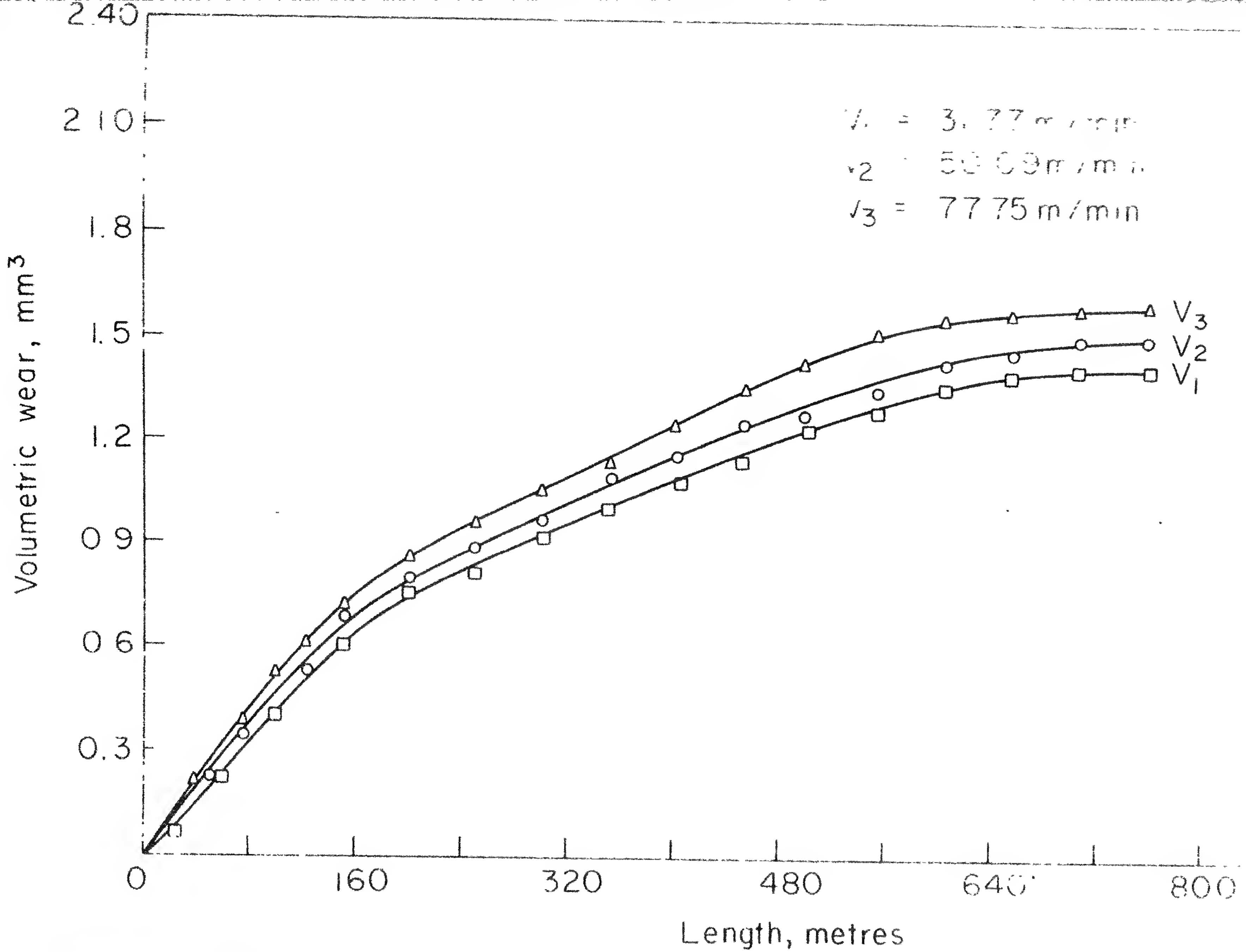

Fig.3.2 Volumetric die wear

[redacted]

in the range of 40 m/min to 90 m/min with appropriate lubrication. The present tests, however, have been carried out under dry conditions for ease in the evaluation of data. The speeds used therefore had to be reduced in dry drawing.

The variation in drawing and separating forces with drawing length is shown in Fig. 3.3. As soon as the deformation starts, the drawing force almost instantaneously rises to a certain value and remains nearly constant throughout the drawing. The separating force, on the other hand, increases rapidly upto a certain drawing length and then the increase is gradual. This curve thus has two different slopes. This change over point comes earlier, i.e., at smaller drawing length, at lower drawing speed.

Both separating and drawing forces decrease with increase in drawing speed (Fig. 3.4). The reduction in the magnitude of the forces are almost of the same order. Fig. 3.5 shows the variation in the ratio of separating force to drawing force. This ratio increases in the initial drawing stage but remains more or less constant during the remaining length of drawing. Since there is hardly any change in the drawing force, the variation in this ratio is primarily due to the variation in the separating force.

As the drawing process continues the exit diameter of the die keeps on increasing. This increase in the exit dia-

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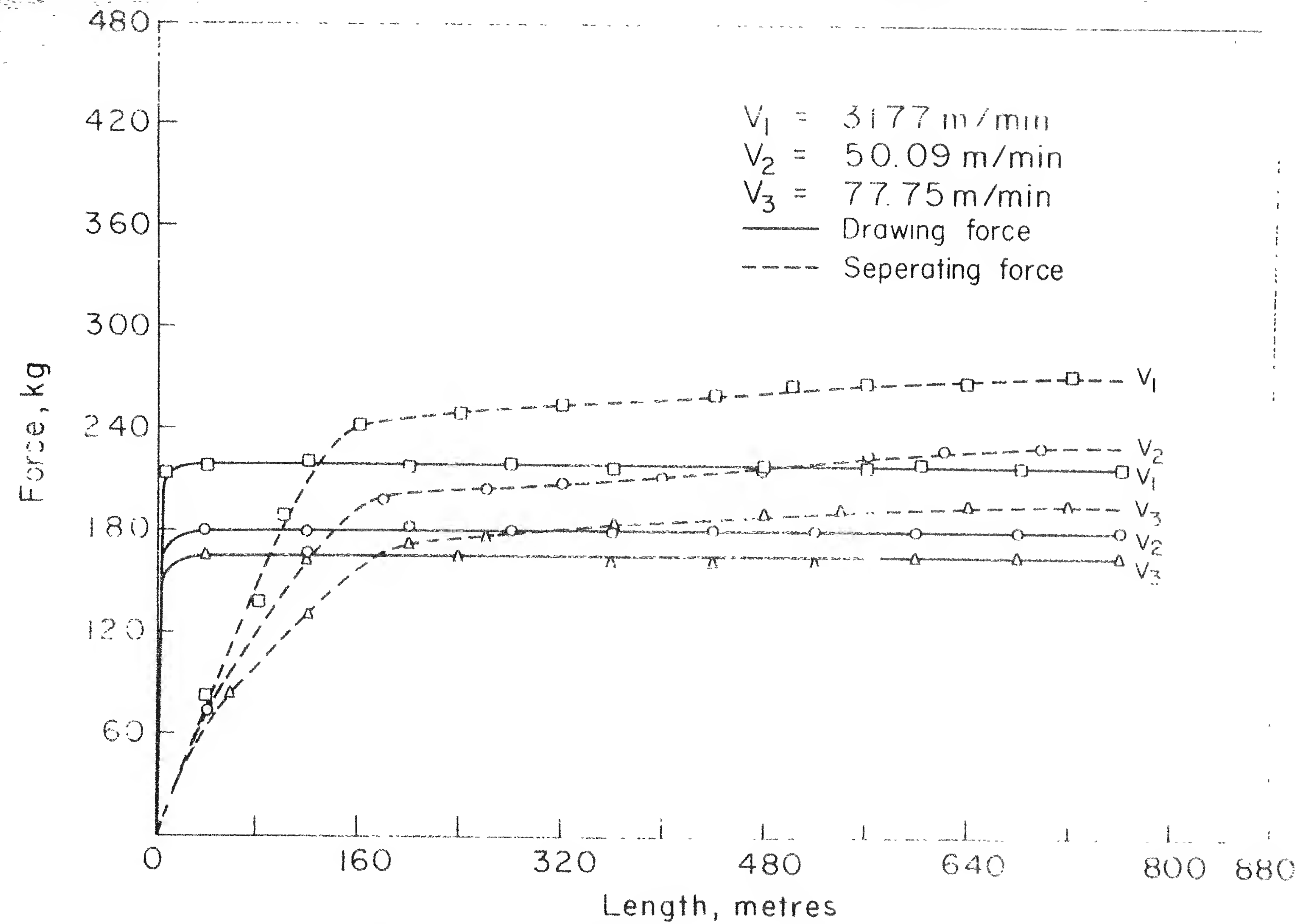

Fig.3.3 Variation of drawing and separating force with drawing length

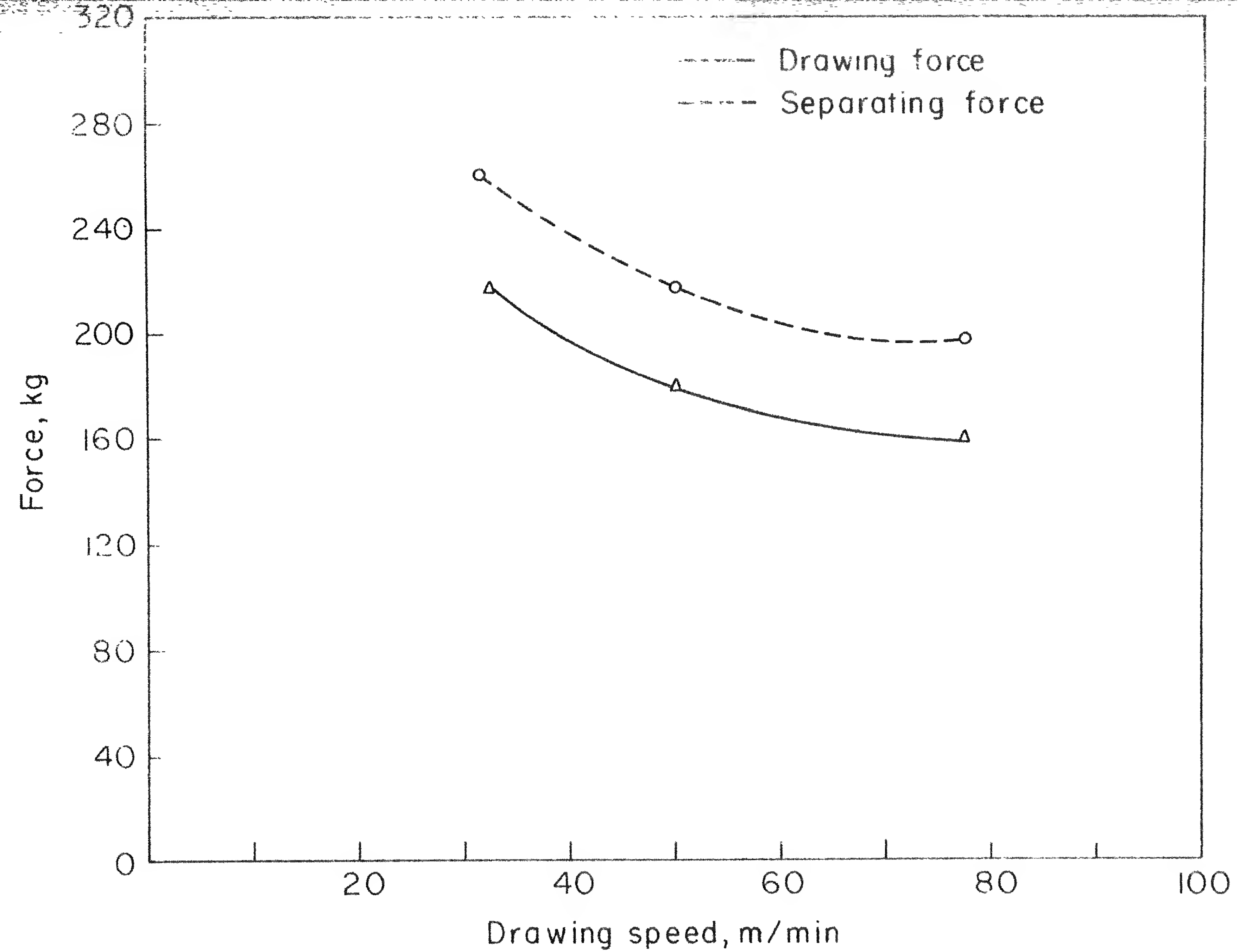

Fig.3.4 Variation of drawing and separating force with drawing speed

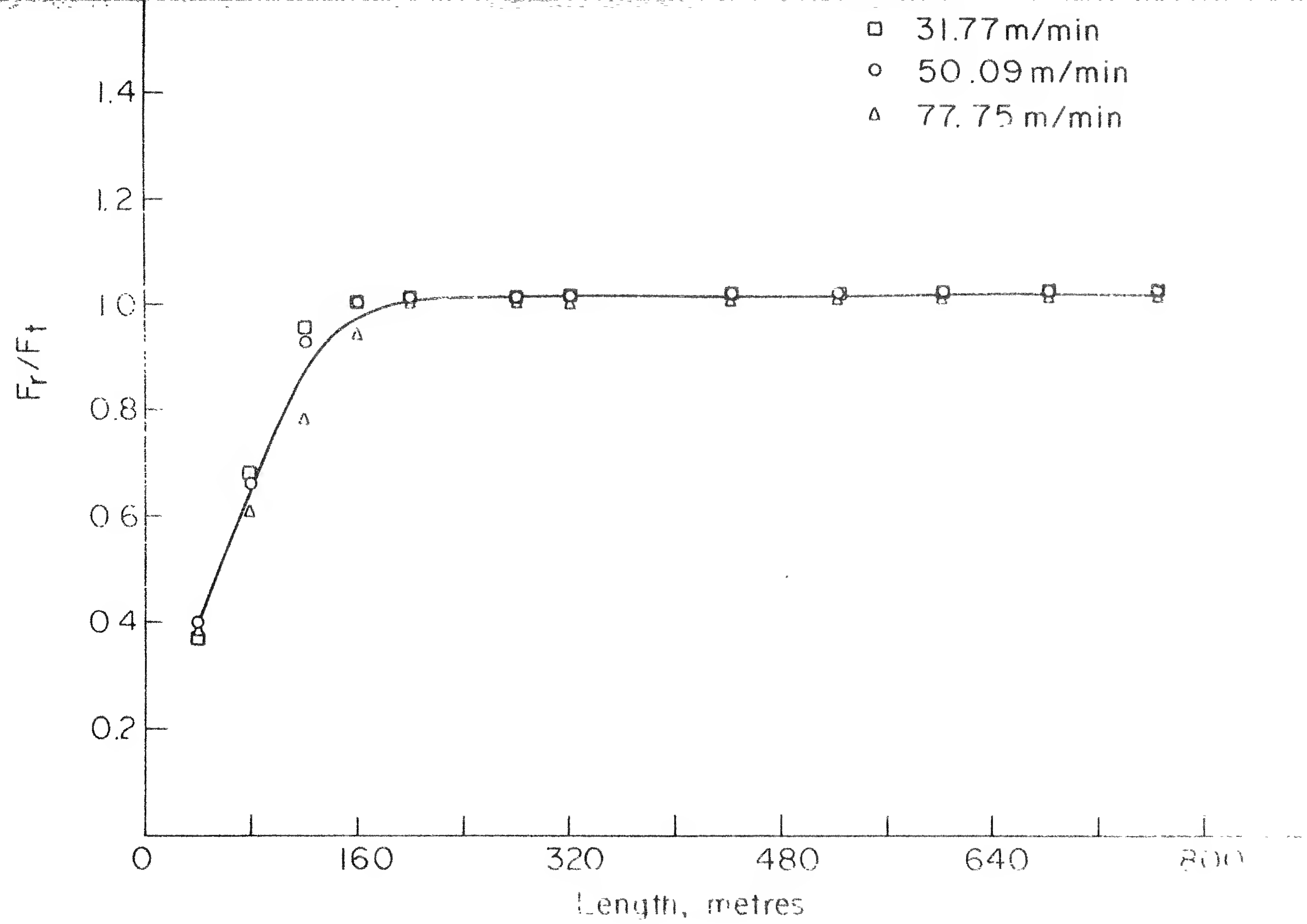

Fig 3.5 Variation of F_r/F_t with

[redacted]

meter is reflected on the drawn wire and can also be evaluated from measurements of the diameter of drawn wire. Fig. 3.6 shows the variation f the diameter of the drawn wire with drawing length. Initially the change in the wire diameter is negligible, thereafter it increases gradually. At higher drawing speeds, the rate of increase in the diameter of drawn wire is higher causing higher wear rate. The increase in the diameter of the wire is about 4 % to 7 % of the initial exit diameter of the die at different drawing speeds.

Earlier results (Fig. 3.2, 3.6) show that volumetric wear rate is more during the initial stages of drawing, but this is not reflected on the change in the drawn wire diameter. This is primarily because the wear during the initial length of drawing does not occur in the bearing zone but is mainly confined to the deformation zone. Subsequently the bearing zone also gets affected and this gets reflected on the drawn wire diameter.

As the diameter of drawn wire increases with drawing length, the effective reduction in area comes down. The instantaneous reduction in area is calculated and plotted in Fig. 3.7. The curves show that the rate of decrease in reduction is more at higher drawing speeds.

It is important to enquire into the mechanism of friction in wire drawing, since the phenomenon of friction and wear

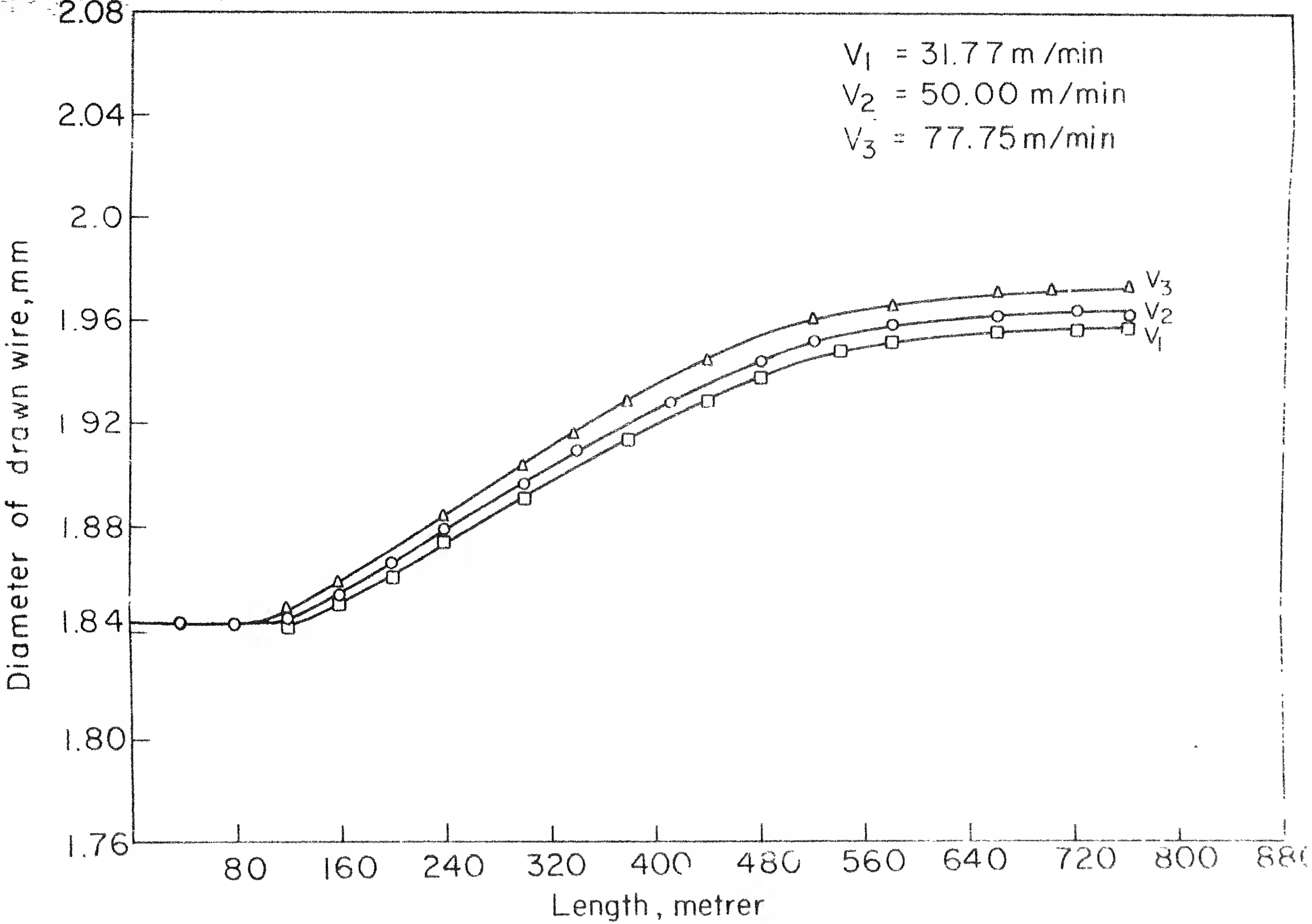

Fig.3.6 Dimensional accuracy of drawn wire

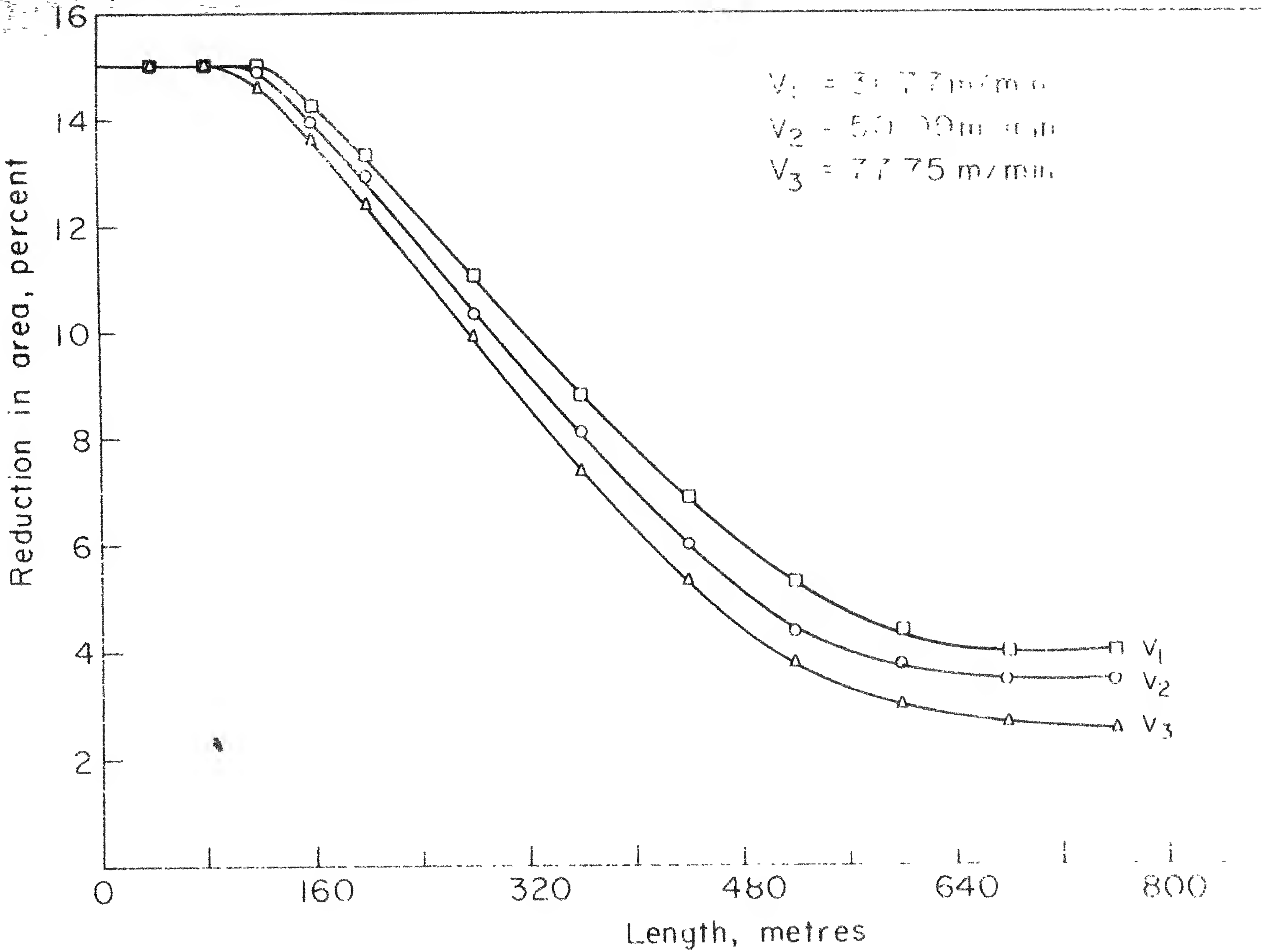

Fig 3.7 Variation of reduction in area with drawing length

[redacted]

are closely related. The method of determining the coefficient of friction, first suggested by MacLellan [3] was based on concurrently measuring the pull and the force required to hold together the two halves of a longitudinally split die. He did not consider the effect of bearing zone and gave the following equation for evaluating the coefficient of friction μ :

$$\mu = \frac{\text{Cot}\alpha - \pi(\frac{F_r}{F_t})}{1 + \pi(\frac{F_r}{F_t})\ \text{Cot}\alpha} \tag{3.1}$$

where,

α = die semi cone angle, in deg.

F_r = separating force in kg; and

F_t = drawing force in kg.

Yang [2] modified the above equation by taking the bearing length into consideration and by assuming the mean coefficient of friction in the conical part and in the bearing zone to be the same. His expression for μ was

$$\mu = \frac{\Delta A\ \text{Cot}\alpha + \pi D_a L - \pi(\frac{F_r}{F_t})\Delta A}{(\frac{F_r}{F_t})\ \pi(\Delta A\ \text{Cot}\alpha + \pi D_a L) + \Delta A} \tag{3.2}$$

where,

$\Delta A = \frac{\pi}{4}(D_b^2 - D_a^2)$,

L = bearing zone length,

D_b = Initial diameter of wire, and

D_a = Final diameter of wire.

The Table No. 3.1 shows the values of coefficient of friction evaluated from the experimental results using equation (3.2). It shows that the bearing zone length does effect the value of the coefficient of friction and in all the cases gives higher value of μ. The μ values obtained by considering the bearing zone length, plotted in Fig. 3.8, shows the variation with drawing length. The coefficient of friction is high in the beginning but soon drops down and then remains more or less constant. The curve also indicates that drawing speed has little effect on coefficient of friction.

The experimental results show that the volumetric wear rate of die is high during initial drawing and the separating force also increases rapidly in the zone. This is because the coefficient of friction is very high as the drawing starts, which inturn increases the interface temperature. This rapid increase in the temperature heats up the die and the resulting expansion of the die causes rapid increase in the separating force. After a certain length of drawing, the coefficient of friction stabilizes and becomes almost constant and so does the temperature. During subsequent drawing the increase in the temperature is apparently small and as indicated by marginal increase in the separating force. The μ value also as a consequence decreases slightly. It may also be pointed

[redacted]

Table 3.1

Drawing length metres	Coefficient of friction					
	77.75 m/min		50.09 m/min		31.77 m/min	
	with bearing length	without bearing length	with bearing length	without bearing length	with bearing length	without bearing length
40	0.8061	0.754	0.76	0.7136	0.800	0.7522
80	0.5015	0.460	0.4549	0.4151	0.4452	0.405
120	0.3857	0.347	0.320	0.2836	0.3126	0.276
160	0.3100	0.279	0.276	0.2394	0.267	0.231
200	0.2875	0.249	0.268	0.230	0.266	0.2288
280	0.2818	0.240	0.2602	0.220	0.2617	0.222
360	0.2751	0.231	0.2577	0.2149	0.2599	0.2180
440	0.2720	0.2252	0.255	0.2099	0.2572	0.2129
520	0.2698	0.2208	0.253	0.2052	0.2563	0.2099
600	0.2682	0.2180	0.247	0.1985	0.2598	0.2070
680	0.2645	0.2139	0.240	0.1922	0.2526	0.2040
740	0.2631	0.2139	0.240	0.1922	0.2526	0.2040

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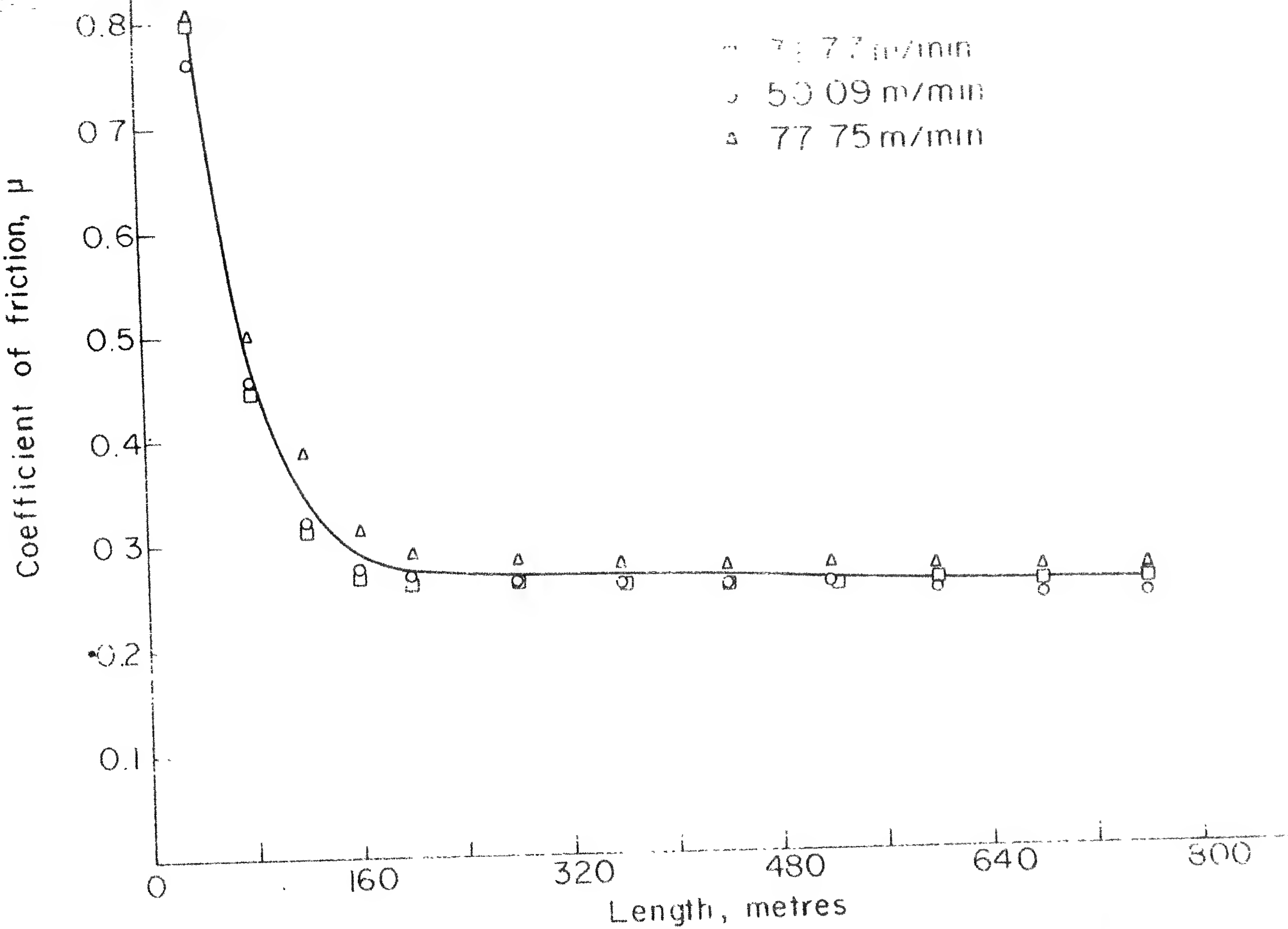

Fig.3.8 Variation of coefficient of friction with drawing length

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out that continuous wear of the die during drawing will also cause a decrease in the rate of increase of the interface temperature and the coefficient of friction due to decrease in the percentage reduction. The interface temperature is not likely to affect the drawing stress since wire stays in the deformation zone for a short time. Though the die is wearing out continuously while drawing, the drawing force remained more or less constant. This may be because of the nature of deformation taking place inside the die.

During initial drawing the diameter of the drawn wire did not change much but the wear rate as well as increase in the separating force was quite high. To confirm whether or not the opening-up of the split die had any effect on the diameter of the drawn wire, the fin thickness formed on the wire was measured. The fin thickness in all cases was found to be less than 0.02 mm for the 2 mm diameter wire used.

Normally the life of a wire drawing die is defined in terms of the length of drawn wire without sacrificing the accuracy of the drawn wire. That is the die is discarded when the diameter of the drawn wire exceeds a certain value. Since the die wear and dimensional accuracy of drawn wire show a related pattern the life of the die can also be evaluated in terms of volumetric wear.

[redacted]

The forces and coefficient of friction do not appear to be useful parameters for estimating the die life. The volumetric die wear and dimensional accuracy of the drawn wire appear to be the parameters for the evaluation of die life (Fig. 3.9). Curves relating these parameters could therefore be considered for developing an equation for die life.

In estimating the volumetric wear of wire drawing die radio-tracer technique has been proved to be very sensitive and accurate. This technique has been used by many researchers [17-21] in different fields of study. An attempt has been made to verify the results obtained by this technique with those of obtained by split dies. Die wear was therefore, evaluated using γ-γ coincidence technique used by Jajoo [21]. The results are plotted in Fig. 3.10. The wear values evaluated from split die experiments are also shown in the same figure for comparison. It shows that the radio-tracer technique gives fairly accurate results. The main advantage of this radio-tracer technique lies in the fact that it is very sensitive and the wear values can be evaluated by drawing wires for a small length. Since the wear curve beyond the initial region is reasonably linear, the wear values at the end of die life can be evaluating by extrapolation. Thus the time for experimentation can be considerably reduced.

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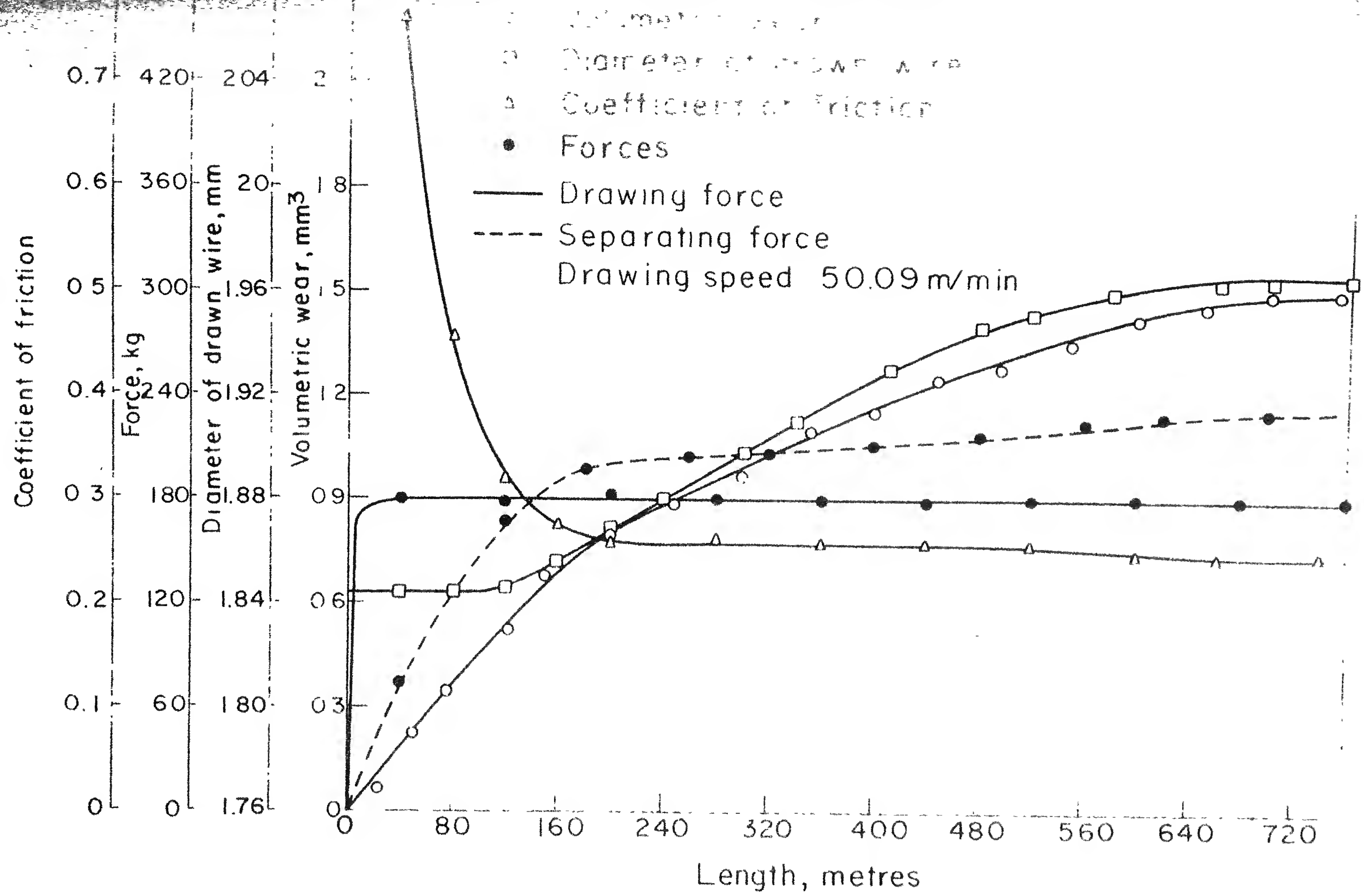

Fig. 3.9 Volumetric wear, diameter of drawn wire, forces and coefficient of friction vs drawing length

[redacted]

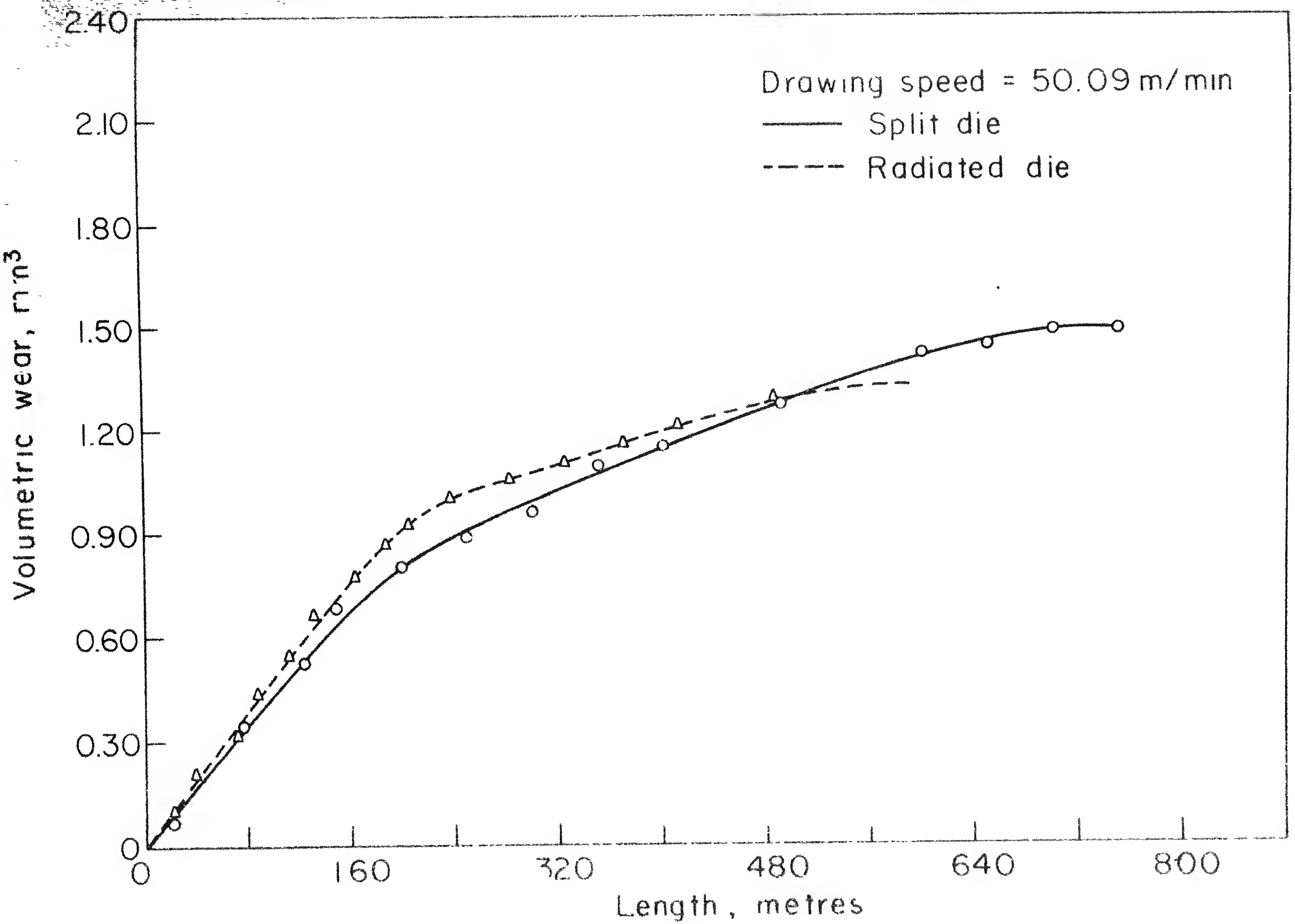

Fig. 3.10 Volumetric die wear

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CHAPTER - IV

CONCLUSIONS

The experimental results have been obtained during wire drawing of mild steel using HSS dies under dry conditions. The die wear as well as the separating force have been measured using split dies. Results clearly indicate that the bore of the die at all sections along its axis remains almost circular. The diametral change however is different with maximum wear occuring near the centre section.

The drawing force remains almost constant throughout the drawing operation but the separating force initially increases rapidly then the increase is gradual. With increase in the drawing speed both drawing and separating forces decrease. The measurement on drawn wire indicate that the change in diameter in the initial stages of drawing is negligible but increases gradually thereafter.

The average coefficient of friction calculated using an indirect method. The values shows that bearing zone length does effect its value significantly. The coefficient of friction is very high as the drawing starts and decreases only slightly during subsequent drawing.

Results clearly indicate that the die wear and the diameter of drawn wire are the main parameters which could be

considered for the purpose of evaluating the die life. For evaluating volumetric die wear, the γ-γ coincidence technique appears to be quite sensitive and accurate.

Scope for Further Work :

The present work should be extended to study the effect of drawing speed and reduction, the two main input parameters, and attempt should be made to establish an equation for predicting die life. Further the work should be carried out under wet conditions using appropriate lubricant.

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APPENDIX I

Wire Drawing Machine Specifications

Make	:	Wire Machinery Manufacturing Corporation Limited, Calcutta
Model	:	WM/400/1, Machine No. 1088
Drawing Speed	:	77.75 m/min (Capstan rotating speed)
Capstan circumference	:	1.25 m
Motor	:	SIEMEN Make, 20 HP, 960 r.p.m.
Capacity of the Machine	:	Maximum diameter to be drawn 4 mm (Ferrous) 6 mm (Non-ferrous)
Maximum tensile load	:	50 kg/mm^2 (M.S.)

APPENDIX II

LVDT Specifications

Make	:	Starret electronics gauge, U.S.A.
Range	:	0.0001 inch (0.00254 mm) to 0.006 inch (0.1524 mm)
Serial No.	:	238
Power input	:	115/230 Volts, 50-60 Cycles
Transducer No.	:	712-1

APPENDIX III

Error Calculations

$$\text{Expected activity} = \frac{N \sigma_a \phi V \lambda tr}{3.7 \times 10^{10}} \text{ Ci}$$

where σ_a : 17×10^{-24} cm^2

ϕ : 5×10^{12} neutrons/cm^2-sec.

NV : $\dfrac{\text{Mass of } Co^{59} \text{ in sample} \times 6.023 \times 10^{23}}{59}$

λ : $\dfrac{0.693}{T_{1/2}}$,

where $T_{1/2}$: 5.3 years

tr : irradiation time

Calculation of Absolute Activity

$$\text{Activity: } N = \frac{C_1 C_2}{C_{12}} \times \frac{1}{3.7 \times 10^{10}} \text{ Ci}$$

where C_1 is the count rate of channel A, C_2 the count rate of channel B and C_{12} the coincidence count rate.

Error Analysis

$$AVA = \frac{A_1 + A_2 + \ldots\ldots A_n}{n}$$

where A_1, A_2,...., A_n are set of count rate readings in channel A.

$$ERR\ A = \left(\frac{AVA}{n} + \text{Back } A \right)^{1/2}$$

where ERRA is the Error and Back A is the Background count rate.

Similarly for channel B and coincidence unit,

ERR B and ERR AB can be calculated respectively.

$$SIG = [(AVA - BACK\ A) \times ERR\ A]^2 + [(AVB - BACK\ B) \times ERR\ B]^2$$

$$ERAC = [(AVA-BACK\ A) \times (AVB-BACK\ B) \times ERR\ AB]^2 + AVAB^2 x SIG$$

$$ERRAC = [ERAC/AVAB^4]^{1/2}/(3.7 \times 10^{10})$$

where ERRAC is the final error in the activity

Cumulative Error Calculations:

l_i = length of the wire

N_i = Activity

σ_i = ERROR

f = factor = $(l_{i+1} - l_i - 1)/2$

Cumulative activity = NC (i+1) = $N_i + (N_i + N_{i+1})f + N_{i+1}$

Cumulative activity error

$$= \sigma_{c(i+1)} = [\sigma_i^2 + (\sigma_i^2 + \sigma_{i+1}^2)\ f^2 + \sigma_{i+1}^2]^{1/2}$$

Activity of the irradiated Die = 5 mCi

Die weight = 27.26 grams

Activity per unit gram of die material = 0.1834 mCi/gm

Absolute Activity is converted into grams of die material that wore out. This is converted into volumetric wear by taking H.S.S. density 9.82 grams/cm^3.

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